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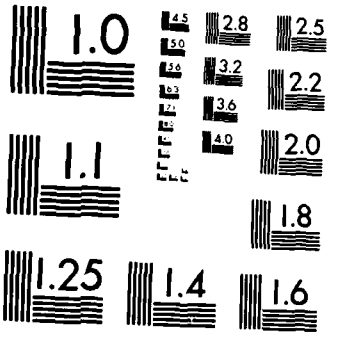

MT-CWR-85-001

UNITED STATES ARMY WELDING RESEARCH AND DEVELOPMENT TOPICAL AND COORDINATION MEETING

February 5-8, 1985

Colorado School of Mines
Golden, Colorado 80401

Submitted to:

United States Army Research Office
%Dr. Andrew Crowson
P.O. Box 12211
Research Triangle Park, North Carolina 27705

Submitted by:

David L. Olson
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March 19, 1985

CENTER FOR WELDING RESEARCH
Colorado School of Mines
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ABSTRACT:

The United States Army Welding Research and Development Topical and Coordination Meeting, February 5-8, 1985 was held at the Colorado School of Mines to achieve the following objectives: (1) Identify the technical expertise at each of the U.S. Army welding research facilities and to increase communication between facilities. (2) Methods for information exchange will be established (i.e. establish annual Army Welding Research Meetings). (3) Possible solutions to specific technical joining and assembly problems will be introduced and discussed. (4) Potential research projects will be identified which have the greatest possibility of being meaningful to U.S. Army concerns.

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Abstract

The United States Army Welding Research and Development Topical and Coordination Meeting, February 5-8, 1985 was held at the Colorado School of Mines to achieve the following objectives: 1) Identify the technical expertise at each of the U.S. Army welding research facilities and to increase communication between facilities. 2) Methods for information exchange will be established (i.e. establish annual Army Welding Research Meetings). 3) Possible solutions to specific technical joining and assembly problems will be introduced and discussed. 4) Potential research projects will be identified which have the greatest possibility of being meaningful to U.S. Army concerns.

1.0 THE OBJECTIVES OF THE FIRST WELDING RESEARCH AND DEVELOPMENT TOPICAL AND COORDINATION MEETING

With the increasing requirements for weld integrity and higher productivity, and the continuous introduction of new engineering materials, welding engineers need high quality sources of information and continual education into welding fundamentals and practice. Many industrial organizations have taken advantage of an extended welding/joining and assembly experience by having periodic technical meetings involving representation and participation of welding engineers and researchers from their various research, development and manufacturing facilities. These meetings have been very successful for they have achieved an excellent information exchange and cooperation between the various facilities. The specific welding concerns are discussed and prioritized. Specific topics are promoted for research support.

This meeting was designed to achieve the following objectives.

1. Identify the technical expertise at each of the U.S. Army welding research facilities and to increase communication between facilities.

2. Methods for information exchange will be established (i.e. establish annual Army Welding Research Meetings).

3. Possible solutions to specific technical joining and assembly problems will be introduced and discussed.

4. Potential research projects will be identified which have the greatest possibility of being meaningful to U.S. Army concerns.

2.0 SPECIAL TOPICAL JOINING SESSION

The first day of the meeting was designed to be an information transfer from invited scientists from various Federal supported welding R&D groups which are using joining concepts and processes that are not common and offer unique advantages. Six technical seminars were given and described below:

2.1 Dr. Paul Burgardt

Nuclear Joining R&D Group
Bldg. 779
Rockwell International
Rocky Flats Plant
P.O. Box 464
Golden, Colorado 80401

"Electron Beam Welding"

The physics associated with electron beam welding and the physical limitations of the process were discussed. The advantages and disadvantages of particular electron beam welding systems were described.

2.2 R. Alan Patterson
Welding Research Group
Los Alamos National Laboratory
Los Alamos, New Mexico

"Explosive Welding and Cutting"

The utilization of explosive welding processes and their specific advantages in making dissimilar metal joints were discussed. The nature and integrity of the joint interface have been investigated and found to be acceptable for most engineering applications. Explosive welding and cutting offers some major advantages where assemblies were made in the field. This process offers a unique energy source, but to achieve full utilization of this process will require both research to achieve predictable behavior and education for personnel to use the process effectively.

2.3 J. Randy Roper
Nuclear Joining R&D Group
Bldg. 779
Rockwell International
Rocky Flats Plants
P.O. Box 464
Golden, Colorado 80401

"Solid State Bonding"

A special low temperature solid state bonding process was introduced. This process uses a thin silver coating on the surface to be bonded and on bonding the silver makes an interlayer between the bonding surfaces. Parts have been bonded at 200C with a 10,000 psi bonding pressure and 10 minutes of bonding time. This low temperature and pressure allows precision joints to be made with minimal distortion and with avoidance of low temperature altrotropic phase transformation. The process is extremely useful to the assembly of precision parts and dissimilar materials.

2.4 Dr. Hershell B. Smartt
Materials Science Division
(ILF-231)
Idaho National Engineering Laboratories
EG&G Idaho
P.O. Box 1625
Idaho Falls, Idaho 83415

"Advance Welding Controls"

Advance sensing and control concepts for arc welding were discussed. The new research approaches and tools for studying sensing and controls were introduced. Advancements in sensing and controls will result in not only higher productivity, but with in situ inspection higher weld integrity will be achieved.

2.5 Dr. Tom Siewert
Division 430
National Bureau of Standards
325 Broadway
Boulder, Colorado 80303

"Weldability of Steel with Reduced Gap"

Narrow gap submerged arc, gas tungsten arc with cold or hot wire feed, and gas metal arc welding processes were described and compared for heavy section applications. Advantages and disadvantages for selection of a narrow gap process were given. The methods to control narrow gap welding processes for carbon and alloy steel were discussed.

2.6 Russell Chihoski
Martin Marietta Aerospace
P.O. Box 179
Denver, Colorado 80201

"Advanced Concepts Relating to the Selection of Weld Parameters for Welding of Aluminum"

The influence of the speed of welding on the state of stress associated with a weldment was introduced. The nature of defects in the welding of aluminum were related to the welding process. Review of the types and distribution of porosity in aluminum weld metal was given. Philosophical discussion as to the lack of true development work in welding was discussed. Support is given to research and product improvement but government, industry and universities do not appear to appreciate the important link that a development group can give between the supported research and product improvement efforts. Chihoski was concerned about how specifications, codes and standards are made and implemented. He was also concerned with the cost that our present code and specification practice is producing in terms of productivity and creativity.

3.0 PANEL OF INVITED EXPERTS

The panel of invited experts were the six technical seminar speakers, who are listed with their expertise in section 2.0. Professor Jerry E. Jones of the Colorado School of Mines lead the panel discussion which was centered around six questions which are described in section 3.1. All of the participants took part in this discussion.

3.1 Questions for discussion and a summary of the response.

1. What technologies are ready to be transferred from laboratory practice to full utilization in the manufacturing and repair of United States Army assemblies?

a. Ceramic grade (i.e., sol gel flux) welding fluxes which should assist in the use of consumable welding processes with feed back controls.

b. Laboratory advances in robotic welding system can now be used in manufacturing and repair welding.

c. Use of capacitance measurement system to evaluate moisture content of electrodes.

d. Use of narrow-gap welding technology.

e. Electron beam welding can now be applied, including the use of cold wire feed systems.

f. Quantitative NDE techniques can be transferred to manufacturing.

2. What new materials are under development which should be brought to the attention of United States Army Personnel involved in joining?

a. The Army personnel are very aware of the new engineering materials, but would like more opportunity to assist in the material selection process for any given assembly.

b. Metal matrix composites.

c. Al-Li alloys provide enhanced modulus-to-weight ratios.

d. HIP'ed stainless steel materials.

e. Rapid solidification and non-ingot technology metals.

3. What advances do you foresee in welding/joining energy sources and control systems?

a. Hybrid welding system which will combine GTA and laser welding or GMA and laser welding.

b. Higher energy lasers and a more compact power unit.

c. Robotic welding systems with adaptive feedback.

d. Homopolar pulse generation as a welding power source.

e. Tunable laser systems for improved plasma coupling.

f. Microwave energy systems for ceramic joining.

g. Laser assisted chemical vapor deposition (CVD) for low pressure plasma coatings.

h. Improved plasma efficiency using low pressure plasmas for joining of composites.

i. Use of MASER systems as a welding energy source.

4. What advances do you foresee in inspection technology and techniques?

a. On line inspection (defects and chemistry) with feedback controls.

b. Laser holography as applied to metal joints.

c. Computer aided tomography with "real-time" radiography.

d. Computer aided image analysis and using higher resolution (smaller cell size) detectors for real-time radiography.

e. Computer evaluation of NDE results, including such advancements as pattern recognition.

f. Non-contact ultrasonic transducers and the use of longitudinal shear waves as opposed to compressive waves.

g. Advanced dye penetrant systems capable of discrimination of defects and reduces requirement for surface preparation.

h. Improved fracture mechanics applicability to determine the required sensitivity of NDE systems. Advances in mechanical testing to determine the information needed to establish NDE criteria.

5. What will be the joining and material manufacturing concerns in the year 1995? What welding and joining research and development areas do you consider essential if industry and universities are going to meet the future needs of the United States Army?

a. Advanced consumables and the universal consumable for a given alloy system.

b. The joining of composites. NDE of composite joints will require a major research effort.

c. A more weldable aluminum alloy.

d. Quantitative non-destructive testing.

e. Welding of higher strength steels such as HY180.

f. Reducing the levels of tramp elements in steels as mini-mills begin to increase their market share.

g. Effects of minor impurity elements on the weldability of materials. Inclusion shape control using minor element additions.

h. Solid state bonding technology needs to be more thoroughly investigated.

i. Better economic analysis and computer modeling. Repair welding needs to be addressed.

j. Establish the uses and properties of explosive welds and high energy inertial welding.

k. Develop a better understanding of tribology concepts. Enhanced wear resistance in various applications.

6. Do the fabrication industries have sufficient competent welding engineering talent to achieve the integrity, reliability and productivity needs of the United States Army?

a. Universities are not preparing mechanical, civil and metallurgical engineers with enough knowledge in the fundamentals of welding processes, welding metallurgy and joint design. All engineers that are going to be involved with materials need at least one course in joining and welding.

b. Technology transfer from laboratories to personnel who are working (out of school) is inadequate. Need to improve continued learning and information transfer to people in the fabrication industries.

c. Need for annual meetings of army personnel to share information and enhance the technology transfer.

d. Need engineers who are interested in development and the practical application of new technologies. More development effort should be spent in transferring new technology to production than in producing "quick-fixes" to current problems.

4.0 UNITED STATES ARMY WELDING CONCERNS

Each U.S. Army Facility represented at this meeting described their Welding Research and Development capabilities. The primary welding concerns of each facility was presented. These concerns will be analyzed by the four invited reviewers to determine which concerns can be effectively addressed by research initiatives.

4.1 Dr. R.A. Weber
U.S. Army Construction and Engineering Research Laboratory
P.O. Box 4005
Champaign, Illinois 61820

4.1.1 Concerns

a. Sensor development for chemical analysis during welding

b. Weld quality

c. Hydrogen cracking in armor steel

d. Gaseous impurities in aluminum welding

4.1.2 Research Efforts at CERL

a. Determination of optimized welding parameters for construction materials - for inspectors

b. Correlation of arc spectrum to weld properties

c. Development of adaptive feedback control for GMAW

d. Integration of A/I - Expert systems

e. Development of weld quality monitor

f. Automatic SMAW system to test electrode under reproducible conditions

g. They can extend their research capability to the special laboratories of the University of Illinois

h. They have recently established the Welding Technology Center for the Corps of Engineers at CERL

4.2 Buck A. Schevo
TACOM, AMSTA-RCKM
Warren, Michigan 48091

4.1.1 Concerns

a. Development of plasma - GMA welding system.

b. Develop technology to laser cut and weld armor materials.

c. Development of weld quality monitor to be part of the welding system. This system would stop the welding process if it found lack of penetration, lack of fusion, porosity, cracking, etc.

d. Aluminum welding, especially out of position.

e. Development of new consumables to reduce or avoid preheat and to increase productivity and integrity. Electrodes are desired that anyone can use.

f. Is "H" test satisfactory to quality welds?

g. Residual stress analysis.

h. Development of corrosion preventative primers that won't interfere with welding.

4.2.2 Research Efforts at TARCOM

a. They have effectively used solid state bonded material as a weld insert to make a dissimilar metal joint between aluminum and steel.

b. Robotic welding system evaluation.

c. Interested in high deposition processes.

d. Evaluating narrow gap welding.

4.3 William Ricci
(presented by Dr. R.A. Weber)
Army Material and Mechanics Research Center
Watertown, Massachusetts

4.3.1 Concerns

a. The joining specific strength materials (Al, composites, ceramics, etc).

b. Determination of survival force for welded joints (battlefield environment).

c. Battlefield repair, reliability and maintainability of weld joints.

d. Need for weld quality monitor.

4.3.2 Research Efforts at AMMAC

a. Joining of metal matrix composites.

b. Joining of armor materials.

c. Weld process control.

4.4 George D. Farmer, Jr.
Belvoir Research and Development Center
Ft. Belvoir, VA 22060

4.4.1 Concerns

a. Weldability of 7005 high strength aluminum alloy, including field repairability. The problem is that this alloy takes 21 days to age harden to desired strength. There is a need to determine thermal cycle to reduce this time.

b. Adhesive bonding for field repair.

c. Problem with certification since there are a variety of different types of welds and materials and a large number of small shops doing work for the U.S. Army. Certification at the present is a high cost concern.

d. Need for one universal consumable that can weld all of the aluminum structural materials.

e. Need for hardfacing material for aluminum.

h. Need more engineering graduates from college with welding exposure.

i. Need for specifications for the welding of aluminum structural materials.

j. Need for field identification of alloys.

k. Determination of critical flaw size for their materials, include weld metal. Needs to be quantitative.

4.5 Dr. Peter Thornton
Benet Laboratory
Watervliet Arsenal
Watervliet, New York 12189

4.5.1 Concerns

a. Joining of metal matrix composites.

b. Need interactive (chemistry) control for P/M filler metal welding system.

4.5.2 Research Efforts at Benet Weapons Laboratory

a. Filler metal development for forging hammer reconditioning.

b. Automatic and robotic welding processes.

c. P/M filler metal welding.

d. Welding of high speed steel.

e. Benet Weapon Laboratory has a very capable welding R&D support for their manufacturing facilities.

4.6 Roger Stanton
Army Research and Development Center
SMCAR-SCM-P; Bldg. 355
Dover, New Jersey 07801-5001

4.6.1 Concerns

a. Welding R&D group understaffed.

b. Edge preparations, such as shot blasting, needs to be evaluated.

c. Development of mechanical tests for bond strength for weld overlay bonds.

4.6.2 Research Effort at ARDC

a. They are not doing generic research, but are very involved with upgrading many existing systems and putting into service new weapon systems.

b. A complete spectrum of alloy systems are being used.

4.7 Bruce Buchholz and Harrison Pulsifer
SMCAI-ENM-T SMCRI-AOE
Rock Island Arsenal Rock Island Arsenal
Rock Island, IL 61299-5000 Rock Island, IL 61299-5000

4.7.1 Concerns

a. Development of U.S. Army welding codes for welding steel, aluminum, bronze, etc.

b. Development of a more realistic set of welding specifications and weld tests.

c. Develop better analytical techniques to determine dimensional stability.

d. Develop welding consumables, processes and procedures to use larger diameter wire to promote productivity and cost savings.

e. Develop better GMA welding practice for welding hig strength steels since porosity is a problem for 120 ksi yield strength steel welding.

f. Develop electron beam welding systems with higher pumping speeds. Develop electron beam welding systems that are more acceptable to mass production.

g. Evaluate the influence of the back side water cooling procedures which are being used.

h. Develop post weld heat treatment procedure that is less susceptible to cause cracking in high strength steel welds.

i. Develop welding consumables and welding procedures which will be used on alloy substitutes for stratigic materials.

j. Develop new techniques for positioning of the welding torch and materials being welded in high production facilities.

k. Develop software for qualifying welding technicians.

4.7.2 Research Efforts at Rock Island Arsenal

a. Weld overlay clad research

4.8 Other Concerns Determined from Group Discussion

a. Handbooks are now of lower caliber than in the past. (Example Handbook 158 is inadequate).

b. Investigate resistance welding technology for field repair of structural members. May be necessary to develop special portable power sources.

c. Utilization of shape memory alloys for joining applications.

d. There is a manpower shortage of personnel at U.S. Army facilities with welding engineering experience. This is a major concern since the Army's performance is based on welded assemblies.

e. Establish a codes committee (interagency group) to write more meaningful and standardized welding codes.

f. Increase the awareness of design engineers of requirements necessary to make high production and high integrity welds.

g. Establish information transfer with other welding research organizations; such as the American Welding Institute, Los Alamos National Laboratories, Rocky Flats Joining R&D Group, Edison Welding Institute, etc.

h. Review the state of certification and training for Army personnel who are making production and field welds.

5.0 Report of the Panel of Reviewers

The panel was made up of Professor Ernie Nippes of Rensselaer Polytechnic Institute, Professor Bud Baeslack of Ohio State University, Professor Ray Thompson of the University of Alabama at Birmingham, and Hugh Casey of Los Alamos National Laboratory. The instruction to this panel is given in Section 5.1. The findings of the panel of reviewers are broken up into two sections: Section 5.2 addresses non-technical concerns and Section 5.3 addresses the research needs.

5.1 Panel of Reviewers

1. Reviewers should base their reviews on the presentations of both the invited experts and representatives from the various United States Army facilities.

2. Based on the information presented, reviewers should produce a list of existing, as well as projected, joining and assembly issues which are of concern to the United States Army.

3. On Thursday night, reviewers will participate on a panel to discuss their list of issues. During this panel meeting new issues can be added to the list. From the panel discussion, a list of joining problems will be developed. This list should indicate the priority of the problem based on conceived need.

4. After the panel meeting, reviewers will meet to make a priority listing of research opportunities based on two criteria. First, the research must address United States Army needs; and, second, the research must, based on the reviewers opinion, make meaningful advances toward a solution to those needs.

5. Reviewers will present this priority listing of research opportunities on Friday morning. This list will be debated among the participants and a final list will be established.

5.2 Non-Technical Concerns

a. Interagency code committee needs to be established to develop standard codes and to simplify codes. This committee needs to achieve a methodology to better work with the small business shops.

b. There is an unacceptable welding engineering manpower shortage in all of the Army facilities. This manpower shortage affects cost effectiveness, productivity and ability to translate technical improvements into the manufacturing of assemblies.

c. Design engineers need to be more aware of joining concerns.

d. Need for a forum for interagency communications as to welding and joining concerns.

e. Review of the certification and training practice being used by the U.S. Army in both production and field welding is needed.

f. Establish welding and joining information transfer with National Laboratories (i.e., Los Alamos National Laboratories) and with welding institutes like the American Welding Institute and/or the Edison Welding Institute.

5.3 Technical Research and Development Needs

The panel of reviewers identified the following joining research needs and have listed them in their priority of need.

1. Adaptive process control (sensor development and applications).

2. Real time non-destructive evaluation (sensor development and applications).

3. Consumables.

   a. Multiple purpose filler metal for repair.

   b. Advanced consumables.

   c. Refining of existing consumables.

   d. Flux cored wire development.

   e. New aluminum consumables based on new compositional concepts.

   f. Cold wire feed materials for electron beam welding.

4. Repair technology - including use of robots to reduce need for repair.

5. Weldability and process development for welding metal matrix composites and ceramics.

   a. There is a need to evaluate joining concepts early in the development and selection of new advanced materials.

6. Welding of recycled alloys.

   The concern is in many alloy systems and not just in super alloys. Mini steel mill concepts and the recycling industry are introducing residual contaminants into defense related materials. Project is needed to understand the role of the various

microalloy additions (contaminants) on the weldability and mechanical integrity of structural material which are associated with these recycling streams.

7. "Fitness for Purpose" research.

   The efforts of the last ten years needs to be continued in order to use our mechanical analytical ability to allow for better selection and use of materials which are to be welded. This "fitness for purpose" research should center around weldment materials (fusion and heat affected zones) since they are the least understood due to the heterogeneous nature of their microstructure.

8. High productivity welding of complex joints.

   Methods to automate welding of complex joints needs to be addressed. Adoptive feedback control systems using robotic welding systems is a key issue.

9. Solid state bonding.

   The research need is seen for both low temperature and high temperature bonding processes. Included in this solid state bonding research initiative is explosive bonding, flash, friction and initeral welding processes. Advancements in the utilization of dissimilar metal joined assemblies will result from this solid state bonding research.

10. Quantitative prediction of distortion.

    The lack of data necessary to effectively use the computer analytical techniques that have been generated over the last decade was recognized. It is essential that physical properties for engineering materials, including weld metal, be determined as a function of temperature. Analytical techniques to calculate distortion and shrinkage during multiple pass welding is needed since most structural assemblies of interest are of thickness requiring multiple weld deposits.

11. Ion implantation.

    Ion implantation needs to be used more effectively to produce surface modification for wear and corrosion resistance. Ion implantation coupled with surface modification by laser, EB, and GTA surface heating can improve surface properties.

12. Environmental issues.

Personnel are closely associated in these joining processes which can generate hazardous radiation and fumes depending on the welding process. Research projects should be initiated to alleviate or reduce the health and safety hazards. This concern could be addressed either directly or indirectly by promoting the national health and safety funding agencies to address the standards and concerns of the welding workplace.

UNITED STATES ARMY WELDING RESEARCH AND DEVELOPMENT
TOPICAL AND COORDINATION MEETING

6.0 AGENDA

February 6, 1985 - Petroleum Hall, Green Center

8:00 AM	Coffee & Donuts	
8:30	Introductory Comments: Dr. Andrew Crowson Army Research Office	
	SPECIAL TOPICAL JOINING SESSION (New Information)	
	Session Chairman: Professor Glen R. Edwards, Colorado School of Mines (each presentation 40 minutes long)	
8:45	Dr. Paul Burgardt Rockwell International, Rocky Flats Plant	"Electron Beam Welding"
9:45	Break	
10:00	Mr. R. Alan Patterson Los Alamos Nat. Lab.	"Explosive Welding and Cutting"
11:00	Mr. J. Randy Roper Rockwell International Rocky Flats Plant	"Solid State Bonding"
12:00	Lunch - Freidhoff Hall - Green Center	
1:00 PM	Dr. Hershell B Smartt Idaho National Eng. Lab EG&G, Idaho Falls, Idaho	"Advance Welding Controls"
2:00	Break	
2:15	Dr. Thomas Siewert Nat. Bureau of Standards	"Weldability of Steel with Reduced Gap"
3:15	Mr. Russell Chihoski Martin Marietta Aerospace	"Advanced Concepts Relating to the Selection of Weld Parameters for the Welding of Aluminum"
6:00	Dinner, Freidhoff Hall, Green Center	
7:00-10:00 PM	Evening Session: Petroleum Hall, Green Center, Professor Jerry E. Jones of the CSM Center for Welding Research will moderate a Round Table Discussion between the Topical Seminar speakers and the attendees.	

February 7, 1985 - Petroleum Hall, Green Center

8:00 AM	Coffee & Donuts
8:15	Introductory comments on Welding Concerns and Prioritizing of Problems to be Solved.
	Introduction of Welding R&D Capabilities (15 min.) for each facility. Discussion of Primary Welding Concerns (30 min.) for each facility.
	Session Chairman: Professor Robert H. Frost, Colorado School of Mines.
8:30	Dr. R.A. Weber - U.S. Army Construction and Engineering Research Laboratory
9:30	Dr. B.A. Schevo - U.S. Army Tank-Automotive Command
10:30	Break
11:00	Mr. William Ricci - U.S. Army Materials and Mechanics Research Center
12:00	Lunch - Freidhoff Hall
1:00 PM	Mr. George Farmer - U.S. Army Belvoir R&D Center
1:35	Dr. Peter Thorton - Watervelet Arsenal (Benet Weapons Laboratory)
3:00	Break
3:15	Mr. Roger Stanton - U.S. Army R&D Center, Dover
4:15	Mr. Harry Pulsifer - Rock Island Arsenal
6:00	Dinner - Holland House
7:00	Evening Session: Room 237, Hill Hall, (Metallurgy Bldg)
	Panel of Four Reviewers:

Professor E.F. Nippes, Rensselaer Polytechnic Institute
Professor W.M. Baeslack, Ohio State University
Mr. Hugh Casey, Los Alamos National Laboratory
Professor Ray Thompson, University of Alabama, Birmingham

February 8, 1985 - Middleton Room, Student Center

8:00 AM Coffee & Donuts

8:15 Morning Session:

Session Chairman: Professor David L. Olson, Colorado School of Mines

Panel Report: Prioritize Needs, Discussion

10:00 Break

12:00 Lunch - Wyle Room, Student Center

1:00 PM Afternoon Session (For U.S. Army Research Personnel Only)

Session Chairman: Dr. Andrew Crowson, ARO

1. Methods to Promote Communication/Interaction Between U.S. Army Facilities and Between U.S. Army Facilities and Established Centers of Welding Expertise.

2. Decision on Second Annual Meeting

2:30 Break

3. Selection of Next Agenda

4. Selection of Next Meeting Site

5. Organization of Army Welding Research Discussion Group

7.0 ARMY RESEARCH CONFERENCE PARTICIPANTS LIST

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